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An Introduction to Situation Aware Networks

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Abstract – This paper looks at the application of *Situation Awareness* (SA) in third generation cellular networks. To successfully implement this concept, a number of new technologies must be incorporated into the basestations. This paper considers how adaptive coverage might be realised in practice. In particular, the use of an overlaid sector (or beam) is discussed in detail. The analysis shows that under optimum conditions, an overlaid beam from the home cell can support approximately one quarter of the users in the neighbouring cell.

I. Introduction

In the light of recent Bluetooth developments, wireless communication systems have taken a step towards becoming 'situation aware'. The Bluetooth concept will enable devices such as Personal Digital Assistants (PDA), computers, printers and mobile phones to communicate with each other over short distances [1]. The Bluetooth technology is not only a 'cable replacing' technology, but also enables devices to detect and determine other Bluetooth enabled products and capabilities within their radio range. The detection process is achieved through transmission of relevant information on beacon frequencies.

Although the scenario described above has only been implemented for short-range communication, where devices form instant ad-hoc networks to perform tasks, it would be of great interest if the conceptual ideas could be applied to a cellular network. In this paper, the authors aim to explore the application of *Situation Awareness* (SA) in a cellular network. The paper is divided into two sections. The first section describes the SA concept and introduces a number of required technologies. The second section focuses on a study of *adaptive coverage*. The analysis includes a full system description and a detailed performance analysis. The paper ends with a set of conclusions based on these studies.

II. Applying the situation awareness concept to cellular networks

Current cellular systems such as GSM rely heavily on the fact that their coverage and spectrum usage have been accurately planned to ensure satisfactory performance. There is a need to move away from these stringent planning requirements since planning costs are currently a significant proportion of the total network rollout cost. SA is a step towards the realisation of more dynamic network behaviour. This can be partly accomplished through the utilisation of information that already exists in the system, and partly through the deployment of additional hardware. An example of an SA enabled basestation with appropriate inputs is illustrated in Figure 1.

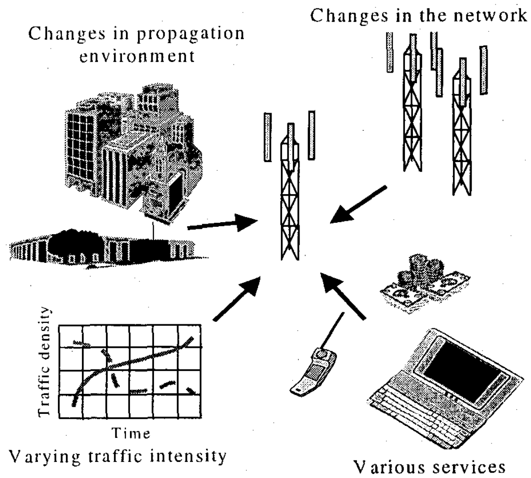

Figure 1: Input parameters for a situation aware basestation

The SA basestation must be able to monitor several parameters that will affect its performance. The goal for the basestation is to optimise its performance according to the current conditions. This can be achieved through the recording and monitoring of the following parameters:

- The severity of the propagation environment
- The type of services the basestation is currently engaged with (voice / video / data / online shopping)
- The traffic intensity
- Any changes in the network – newly inserted basestations, congested basestations, failed basestations.

Each of these categories will have a number of sensors associated with them that will enable the basestation to optimise its performance according to the current situation.

II.I The propagation environment

The basestation must acquire accurate information about its coverage area. In the planning process, an estimation of the local signal strength in a given area will be obtained but this may not be sufficient to guarantee the support of all the various services. Assuming that all mobile terminals have knowledge of their own position, then they will be able to report back geographic samples of their received signal strength, delay spread or any other relevant parameter. Gradually, the basestation will be able to develop an accurate picture of the propagation parameters in its coverage area. Once this information has been acquired, the basestation can take appropriate action.

II.II The service requirements

The basestation will also have full knowledge of how its resources are utilised at any given point in time. On-going services will determine how remaining resources should be allocated, or if any other action is required to successfully complete a current engagement.

II.III Variation in traffic intensity

Variations in the traffic will clearly have an impact on whether the basestation will be able to accommodate more traffic. The aim of the operator is obviously to have the highest utilisation possible. Therefore when congestion occurs in a cell, the basestation should take appropriate action to reduce the congestion by handing connections up or down (in a hierarchical system), or to any of its neighbours with available resources.

II.IV Changes in the network

Finally, the basestation should also have full knowledge of its neighbouring basestations, also any additional micro / pico cells in its area as well as the umbrella cell. All basestations should report their loading level so that when a cell becomes congested, it knows to which basestation a service handover should be requested. Similarly, if a basestation becomes inoperative for any reason, the neighbours should be able to cover the traffic from that region.

For the remainder of this paper, only aspects relating to how the network can obtain a dynamic coverage area will be discussed. The next section introduces the information required to achieve dynamic coverage.

II.V The information requirement to achieve dynamic coverage

Current cellular systems transmit information on their broadcast control channel to enable the mobile terminal to connect to the correct basestation. This information will typically include basestation identity, its type (macro / micro), its position and any other relevant system specific information. To ease the implementation of dynamic coverage, the authors propose that additional transmit power level information is added to this broadcast list. The required information vector now becomes: $I = [id \;\; \mathrm{x\_lat} \;\; \mathrm{y\_long} \;\; \mathrm{Tx}]$ (BS identification, position in latitude and longitude, broadcast control channel transmit power). This information enables the system to calculate the pathloss between itself and its neighbours. This enables the basestation to compute how much it needs to increase (or decrease) its beacon transmit power to obtain the desired coverage. The information also enables the basestations to adapt their coverage intelligently when basestations are inserted or removed from the network. Figure 2 illustrates the concept when a new basestation is inserted into an existing network. The surrounding basestations will detect the new hardware and adapt their coverage areas accordingly to accommodate the new cell.

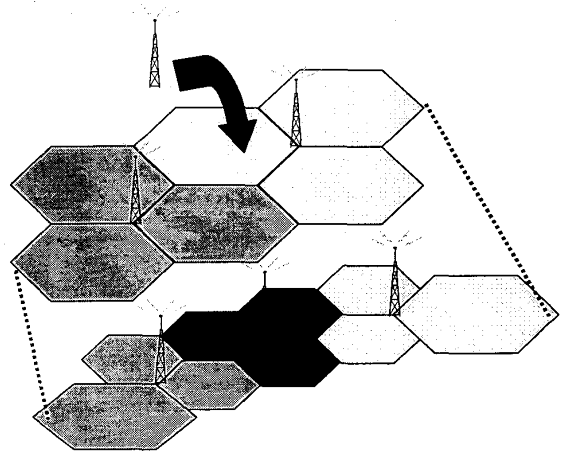

Figure 2: Environment adaptation scenario – insertion of a new basestation

The property described above is very interesting since it allows basestations to be inserted on an ad-hoc basis without the need for network wide re-configuration. In addition, it improves the quality of service when a basestation becomes inoperative, since it facilitates the neighbouring basestations to cover the resulting gap in network coverage. Similarly, if new buildings were constructed, the basestations will detect changes in the propagation environment and re-adjust their power levels to optimise coverage in accordance with the new environment. Small adaptive antenna units will be an important enabling technology to enable the basestations to determine their coverage area more accurately by beam steering their beacon signal in the wanted direction(s) to a much greater extent than current tri-sectored or omni-directional antennas.

III. Supporting users in a neighbouring cell

So far, only the conceptual idea of dynamically adjusting the cell size has been discussed. The rest of this paper will investigate whether this idea is plausible. Some research has already been performed in this area, particularly in the use of adaptive antenna arrays to support users in a neighbouring cell [2][3].

One of the main problems associated with the support of users in a neighbouring cell, is the general need to increase transmit power on both the up and downlink. This will cause unwanted interference. It would therefore be of great significance if one could find a method in which the transmission power did not need to be increased. The aim of the following investigation is to determine what fraction of users in a neighbouring cell can be supported without increasing the transmit power in the home cell.

III.I The overlaid sector

With this technique, the basic configuration of the original antenna can either be omni-directional or tri-sectored. In this example it is assumed that the cells are equipped with omni-directional antennas. Overlaid over this, one or more adaptive antennas with a variable degree beamwidth can be deployed to obtain the required range extension. Unlike the original antenna configuration (which receives all intra and inter-cell interference), users within the overlaid sector will only receive interference from mobile terminals in its sector. Assuming traffic to be uniformly distributed in the cells, and that all the surrounding cells are equally loaded, a 60-degree beam-width would reduce the interference by a factor of six for users within that sector. This will hopefully allow users in a neighbouring cell to connect to the new cell without increasing their transmit power on the uplink.

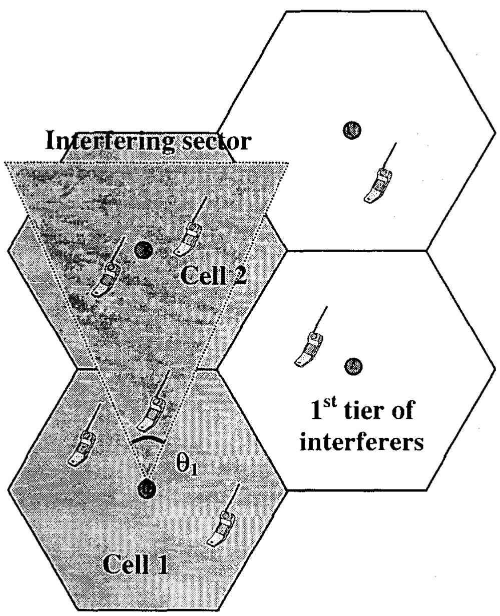

Figure 3: Overlaid sector for the reduced impact of the interference

IV. Simulation Configuration

In order to demonstrate the feasibility of the overlaid sector method operating in the same frequency band, a set of simulations were performed. The simulation was performed using a Monte-Carlo approach with 10 cells, where a given number of users were deployed in each cell. Only data from cell 1 and cell 2 were analysed (see Figure 3). The Eb/No for each user is then calculated. This is followed by an analysis of whether traffic from Cell 2 can be supported under the given conditions using the sectored antenna from Cell 1. The system specifications are listed below in Table 1. The values in brackets signify default values for that parameter (when it is not the independent variable).

Parameter	Specification
Network size	10 basestations
Path loss coefficient	1.6 – 4.4 (3.5)
Cell radii	100 – 1000 m (250)
Shadowing stdev.	0 – 12 dB (8)
Voice Activity factor	1
Chipping Rate	4.096 Mcps
User Bit Rate	8 kbps
Eb/No for uplink	3.3 dB
Overlaid sector (θ_1)	5– 60 ° (30°)
Receiver sensitivity	-120 to -110 dBm (- 120)
Uplink PC error stdev	0 – 1 dB (1)
Uplink PC range	80 dB
Cell load	0.4 – 1.0 (0.67)

Table 1: System simulation parameters

The simulation aims to identify how large a portion of the users in cell 2 could realistically be supported by the overlaid sector from cell 1 under various conditions. It is clear that the most significant limiting factor is going to be the interference. For the users in cell 2 covered by the sector, users from cell 1 will interfere significantly since they are received at much higher power levels. Realistically, only users from cell 2 that are received at Cell 1 above a certain threshold value can be supported. From [4], the receiver sensitivity is assumed to be –124 dBm. The limited processing gain prevents the suppression of users from cell 1 if they are received at a 20dB higher power level. As a result, the first set of simulation results focused on determining the optimum received power level to support the maximum number of user from cell 2.

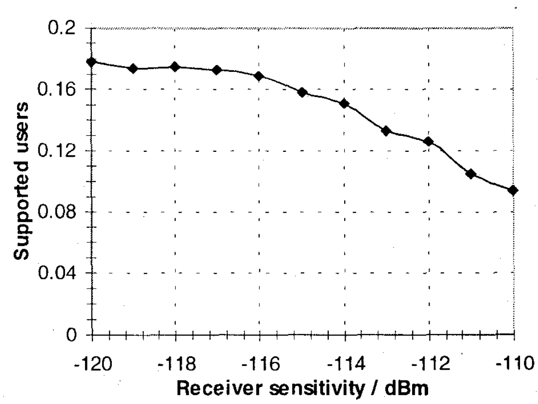

Figure 4: The impact of the receiver sensitivity

For all the results, the term 'Supported users" refers to the fraction of users in cell 2 that can be supported for the given set of parameters.

From Figure 4 it is evident that it is possible to support a larger fraction of the users in cell 2 for higher receiver sensitivity levels. The capacity is almost doubled as the receiver sensitivity is increased from −110 dBm to −120 dBm. The graph also demonstrates that the system saturates when the sensitivity reaches −118 dBm. No significant gain is obtained beyond this sensitivity level.

Another parameter that impacts of the fraction of users in cell 2 that can be supported from cell 1, is the loading of cell 1. This is illustrated in Figure 5, where the fraction of users supported in cell 2 increases from 0.08 to 0.23, depending upon the propagation conditions. The simulation was performed with 0 and 8 dB standard deviation shadowing.

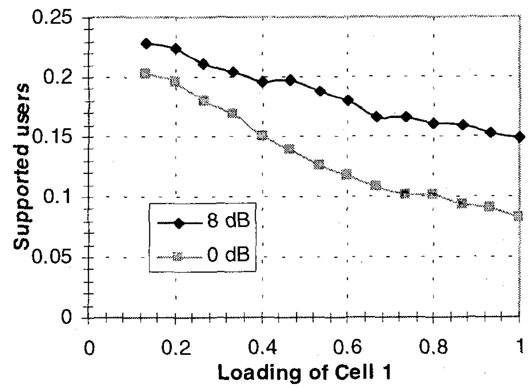

Figure 5: The impact of loading in Cell 1

Another interesting observation from Figure 5 is the impact that shadowing appears to have on the capacity. Shadowing is normally detrimental in cellular systems since it results in increased transmission powers and hence increased interference levels. However, in this particular case it is the interfering part, as seen from cell 1, that is of interest. Therefore, the increased transmit power resulting from shadowing enables a larger fraction of the users in cell 2 to be received in cell 1. The impact of the shadowing component is investigated further in Figure 6 for two different cell radii, 250 and 100 meters.

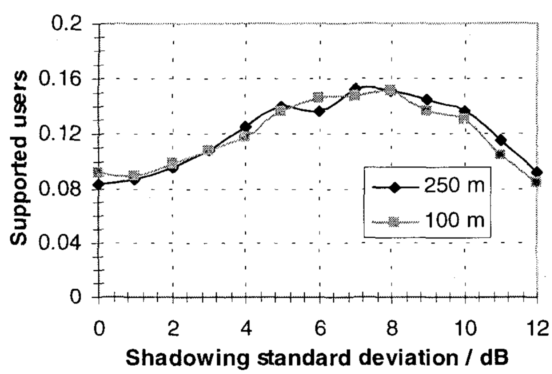

Figure 6: The impact of shadowing on capacity

The fraction of users that can be supported in cell 2 as a function of the shadowing is monotonically increasing up to approximately 8 dB. Higher shadowing standard deviations result in a loss of capacity as the dynamic range of the power control is exceeded, causing the interference levels to increase dramatically. The two different curves for cell radii of 100 and 250 meters do not differ significantly. Figure 7 confirms this observation and shows that the capacity is not altered significantly for cell radii from 100 meters to 800 meters.

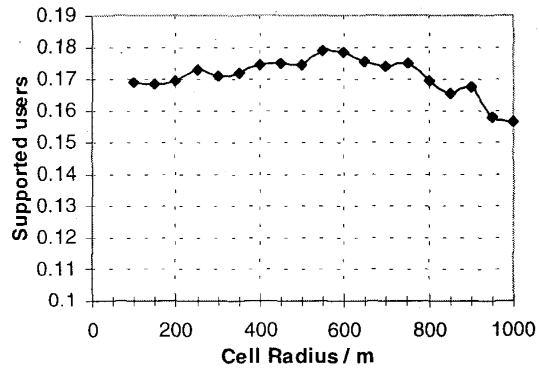

Figure 7: The impact of the cell radius

For cell radii larger than this, the capacity drops off as the maximum range of the system is reached. The range of the overlaid sector depends heavily upon the propagation environment and, in particular, the pathloss exponent. A number of trials were performed to determine range for pathloss exponents from 1.4 to 4.4. The results are shown in Figure 8.

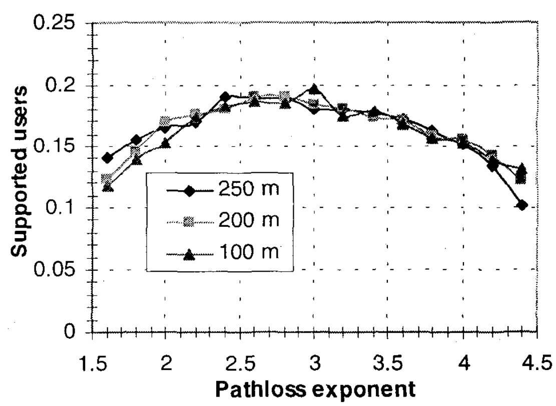

Figure 8 The impact of the pathloss exponent

Three different cell radii were applied in the trial, but very little variation was observed, except for the extreme pathloss exponents at both ends. A maximum in the capacity was obtained for a pathloss exponent of 3. Clearly, for large exponents the range of the overlaid sector becomes small and hence capacity is reduced. For small exponents the range becomes too large, causing unwanted interference.

Finally, the last parameter to be investigated in this study was the overlaid sector angle. In this particular case, cell

2 was assumed to lie at a bearing of 90° from cell 1. Hence, a 60-degree sector from cell 1 is sufficient to cover all of cell 2 (see Figure 3). The results shown in Figure 9 illustrate that the highest capacity is achieved with a 60-degree sector. As the sector angle is reduced gradually in 5° decrements, the capacity decreases monotonically. However, the capacity of the sector was also recorded, and this reveals that the fraction of the users in the sector is increasing.

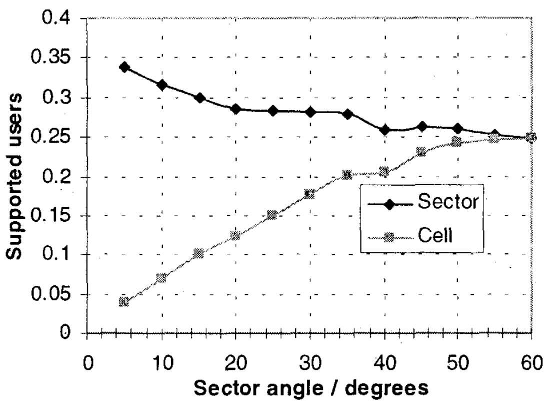

Figure 9: The impact of the sector angle

The results from Figure 9 imply that although the capacity of the sector is reduced for smaller sector angles, the application of two or more smaller adjacent sectors would outperform a single large one. Two adjacent 30° sectors will provided a fractional capacity of 0.28, while a single 60° sector would provide a value of just 0.25.

V. Conclusions

In this paper the concept of Situation Aware Networks has been introduced. The methods address the need for next generation systems to become more flexible and intelligent. Various technologies must be incorporated into the basestation to make the network truly situation aware. One of the fundamental functionalities is the ability to dynamically adjust the coverage area of cells in the network.

The concept of overlaying a steerable sector on a cell already covered by an omni directional antenna was described in detail. An investigation was undertaken to determine how much traffic in the neighbouring cell could be supported by this sector without increasing the uplink transmit power. The results clearly illustrated that this concept was feasible for a wideband CDMA network. It was demonstrated that under optimum propagation conditions a quarter of the users in cell 2 could be supported with the overlaid sector from cell1 (see figure 3).

The factors that most influence the number of users supported in the neighbouring cell were the standard deviation of the shadowing and the angle of the overlaid sector. A shadowing standard deviation of 8 dB was found to give the highest capacity. The reason for this optimum value was that although shadowing tends to increase the interference, in this case it is the signals from the neighbouring cell that are of interest to us. If the shadowing is increased further, the capacity falls as the dynamic range of the power control is reached.

Acknowledgements

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